Rec'd PCT/PTO 06 APR 2005

10/530[illegible]5

PCT/NL 03/00687

Europäisches Patentamt | **European Patent Office** | **Office européen des brevets**

29. 10. 03

REC'D 12 NOV 2003
WIPO PCT

Bescheinigung | Certificate | Attestation

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.

The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

BEST AVAILABLE COPY

Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

02079204.0

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

R C van Dijk

Anmeldung Nr:
Application no.: 02079204.0
Demande no:

Anmeldetag:
Date of filing: 10.10.02
Date de dépôt:

Anmelder/Applicant(s)/Demandeur(s):

DSM NV
Het Overloo 1
6411 TE Heerlen
PAYS-BAS

Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Spun yarn from staple fibres

In Anspruch genommene Prioriät(en) / Priority(ies) claimed /Priorité(s) revendiquée(s)
Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

Internationale Patentklassifikation/International Patent Classification/
Classification internationale des brevets:

D02G3/00

Am Anmeldetag benannte Vertragstaaten/Contracting states designated at date of filing/Etats contractants désignées lors du dépôt:

AT BE BG CH CY CZ DE DK EE ES FI FR GB GR IE IT LI LU MC NL PT SE SK TR

SPUN YARN FROM STAPLE FIBRES

The invention relates to a spun yarn made from staple fibres. The invention further relates to a process for making said spun yarn, to the use of said spun yarn for making various semi-finished and end-use products, and to such products comprising the spun yarn.

Such a spun yarn is known from US 4942731. In this patent publication a spinning method and a spinning apparatus are described, by which what is called a 'single double yarn' can be obtained.

Yarns can be made of continuous filaments, staple fibres or combinations thereof. Natural fibres can be classified in two categories: short staple fibres (cotton like, with typical staple or filament length 15-60 mm) and long staple fibres (wool like, typical staple length 40-200 mm). Synthetic fibres are first made as continuous filaments; they can be subsequently converted into staple fibres by either cutting or stretch breaking processes. Cutting generally leads to a square filament distribution (all filaments having about the same length); although modified systems allow obtaining some variation in the filament distribution. Stretch breaking generally results in staple fibres having a more Gaussian-like distribution of filament lengths. In a stretch breaking process, the filaments are stretched between several sets of rollers operating at different speeds until they break.

Staple fibres can be made into yarn via a process of pulling and twisting strands of parallel fibres, generally referred to as spinning. For this reason, yarn made from staple fibres is called spun yarn.

Industrial yarn spinning processes include the following basic process steps: loosening, carding, drawing and spinning. Loosening refers to separating and optionally cleaning of e.g. baled staple fibres. Carding is the further loosening and separating of fibres, for example by passing them between rotating drums covered with needles. This results in a thin web of partly paralleled fibres, which is formed into a rope-like strand often called a sliver. Combing may then be applied to enhance orientation of fibres and to remove small fibres. During drawing, slivers are drawn out in one or more steps. Several slivers, either of the same or of different staple fibres, may be blended together in order to obtain a uniform fibre density. Mixing staple fibres at the carding stage can also make yarns comprising blends of different natural and/or synthetic fibres. Before feeding to the spinning machine, the sliver may be further

drawn while a slight twist is added, called roving. During spinning, the sliver or roving is further drawn out and a twist is added to provide cohesion of the overlapping fibres, and the yarn is winded onto bobbins. Such a package of winded yarn may be of conical or cylindrical form, and is normally simply referred to as package.

The described spinning process results in a twisted, single-strand yarn, also called single yarn. Depending on the twisting direction applied, such yarns are often referred to as either S or Z yarns. A twisted single-strand yarn is generally rather 'lively', meaning that it tends to twist, tangle, slant or curl round itself when held with insufficient tension. In order to reduce this liveliness, that is to obtain a calm or balanced yarn that can be satisfactorily further processed into e.g. a fabric, it has been generally accepted in industry that two or more strands of single yarns need to be combined in an additional step. Such combining step is normally called folding or plying. A two-fold yarn, or two-plied yarn can, for example, be made by twisting together two single-strand Z yarns with a S-twist, or by plying together a Z and S type yarn. The thus obtained folded yarns may also be stronger and more uniform than single-strand yarns. Such a process, however, is generally rather expensive, because in order to make a two-fold yarn of a certain count, first two singles must be produced at half the count. In particular, whether two packages produced are used, and rewound and combined into a two-fold yarn, or two yarns from two spinning machines are wound directly into a two-fold yarn, the overall productivity of the spinning process is strongly reduced.

The above-mentioned disadvantages of a single-strand yarn are also addressed in US 4942731. The 'single double yarn' described therein is obtained by a spinning method wherein a staple fibre bundle (sliver) after being drafted is separated into a plurality of rows, two in case of a double yarn, and each row is introduced into a separate twisting device for applying a twist, after which the obtained twisted fibre bundles are combined again into a yarn and winded into a package; and is in fact a one-step two-fold yarn.

A disadvantage of the known spun yarn described in US 4942731 is, that it can only be produced on specially adapted machines, comprising a plurality of twisting devices, but not on existing equipment.

It is therefore an object of the present invention to provide a spun yarn made from staple fibres that does not show said disadvantage.

This object is achieved according to the invention with a spun yarn made from staple fibres, which yarn consists of a single strand comprising at least 30

mass% of staple fibres that have been obtained from a precursor continuous multifilament yarn having a tensile strength of at least 16 cN/dtex; a tensile modulus of at least 700 cN/dtex; and a denier per filament of fibre of at most 18 dpf; which staple fibres have an average fibre length of between 40 and 180 mm; and essentially no crimp;
and which spun yarn has a twist level characterized by an α twist coefficent (Koechlin law) of 60 -100 $t.m^{-1}.(m/g)^{-1/2}$.

The single-strand spun yarn according to the invention can be made on existing, less complex spinning equipment, with high productivity and at relatively low cost. The spun yarn according to the invention shows very little liveliness, and is found to be calm enough to enable further processing into various semi-finished and end-use products, like woven or knitted fabrics, different kinds of composite yarns, ropes and cords , or fishing lines without the need of first making a folded yarn.

The spun yarns have a straight and shiny appearance, with only little hairiness, much like the high-performance continuous filament yarn (precursor yarn) the staple fibres are made from, and unlike the bulky appearance of conventional yarns generally applied for textile applications like apparels. The spun yarn further shows surprisingly good mechanical properties; its tensile strength is at least 2,5 cN/dtex, but values at the level of 15 cN/dtex have also been found. In addition, cut-resistance may even be at higher level than that of corresponding filament yarn of similar titre. A further advantage is that due to the compact and regular character of the yarn, very regular and uniform fabrics can be made showing advantageous performance when used in protective clothing and the like. The single yarn can be easily combined with other fibres, like other spun yarns, filaments yarns or monofilaments, into various kinds of composite yarns, while maintaining good yarn integrity.

In US 5540980 and US 4802330 it is stated that also balanced single-strand yarns are spun form staple fibres, but these yarns are a in fact composite yarns that are made by spinning a yarn around a core of a continuous fibreglass monofilament or continuous filament yarn, respectively. WO 91/14029 A1 and WO 94/00627 A1 disclose a process for making spun yarn comprising staple fibres made from high performance polyethylene yarn. In the examples both single and two-fold yarns are mentioned, but no specific disclosure of properties, nor of the use of a single-strand yarn is made. The problem of further processing a single-strand yarn is not mentioned nor addressed in these publications. In addition, the reported yarn breaking strengths are at the best about 10% of the breaking strength of a comparative filament

yarn.

The single-strand spun yarn according to the invention comprises at least 30 mass% of staple fibres that have been obtained from a precursor continuous multifilament yarn having a tensile strength of at least 16 cN/dtex ; a tensile modulus of at least 700 cN/dtex; and a linear density or denier per filament of fibre of at most 18 dpf; and which staple fibres have an average fibre length of between 40 and 180 mm and essentially no crimp. In principle any long staple fibres having the indicated properties can be chosen. Such staple fibres can be available as such, or can be made from high performance filament fibres. Examples of suitable fibres include aromatic polyamide fibres, like products available as Nomex®, Kevlar® or Twaron®, polybisoxazole fibres like Zylon®, or highly-oriented polyolefin fibres, such as those based on ultra-high molar mass polyethylene (UHMwPE) like Spectra® or Dyneema®, or mixtures thereof. Such staple fibres are hereinafter also referred to as high strength and high modulus staple fibres, or as high performance staple fibres.

Various polyolefins can be chosen as staple fibres in the spun yarn according to the invention. Particularly suitable polyolefins are homo- and copolymers of ethylene or propylene. In addition, the polyolefins used may contain small amounts of one or more other monomers, in particular other alpha-olefins. Good results are achieved if linear polyethylene (PE) is chosen as polyolefin. Linear polyethylene is here understood to be polyethylene with fewer than one side chain per 100 carbon atoms, and preferably fewer than one side chain per 300 carbon atoms, which may moreover contain up to 5 mol% of or more alkenes that can be copolymerised with it, such as propylene, butene, pentene, 4-methylpentene or octene. Besides the polyolefin the fibre may contain small amounts of solvents or additives that are customary for such fibres, such as anti-oxidants, spin-finishes, thermal stabilizers, colorants, etc. Preferably, the polyolefin fibre, in particular the polyethylene fibre, has an intrinsic viscosity (IV) of more than 5 dl/g. Because of their long molecule chains, polyolefin fibres with such an IV have very good mechanical properties, such as a high tensile strength, modulus, and energy absorption at break. This is also the reason why even more preferably the polyolefin is a polyethylene with an IV of more than 10 dl/g. The IV is determined according to method PTC-179 (Hercules Inc. Rev. Apr. 29, 1982) at 135°C in decalin, the dissolution time being 16 hours, the anti-oxidant is DBPC, in an amount of 2 g/l solution, and the viscosity at different concentrations is extrapolated to zero concentration. Polyethylene of such high viscosity is often called UHMwPE. UMHwPE filament yarn can be prepared by spinning of a solution of UHMwPE into a

gel fibre and drawing the fibre before, during and/or after partial or complete removal of the solvent; that is via the so-called gel-spinning process as for example described in EP 0205960 A, in WO 01/73173 A1, in Advanced fiber spinning technology, Ed. T. Nakajima, Woodhead Publ. Ltd (1994), ISBN 185573 182 7, and in references cited therein.

Preferably, UHMwPE fibres are chosen, because they combine high strength with a low relative density. More specifically, the yarn according to the invention comprises UHMwPE staple fibres that have been made via a stretch-breaking process, since the broader fibre length distribution of such staple results in a yarn with better mechanical properties.

The tensile strength (or strength) and the tensile modulus (or modulus) are defined and determined on multifilament or spun yarns as specified in ASTM D885M, using a nominal gauge length of the fibre of 500 mm, a crosshead speed of 50%/min and Instron 2714 clamps. On the basis of the measured stress-strain curve the modulus is determined as the gradient between 0.3 and 1% strain. For calculation of the modulus and strength, the tensile forces measured are divided by the titre, as determined by weighing 10 metres of fibre.

The spun yarn according to the invention comprises staple fibres that have been obtained from a precursor yarn having a tensile strength of at least 16 cN/dtex, preferably at least 18, more preferably at least 20, at least 25, and even more preferably at least 30 cN/dtex, because higher strength of fibres also results in better mechanical properties of the spun yarn.

The high strength and high modulus staple fibres comprised in the single-strand spun yarn according to the invention have been obtained from a filament yarn having a linear density of at most 18 denier per filament (dpf), preferably at most 14, more preferably at most 10 dpf, and even more preferred at most 6 dpf. The lower the linear density of the fibres, the thinner the spun yarn can be, since a certain minimum number of fibres is needed in a cross-section to give a yarn of sufficient integrity. Furthermore, the lower the linear density of the fibres, the higher the tensile strength of the spun yarn at a constant yarn titre.

The staple fibres in single-strand spun yarn according to the invention have an average fibre length of between about 40 and 180 mm. A minimum length is needed to provide sufficient strength and integrity to the yarn. Increasing fibre length generally results in improved mechanical properties of the spun yarn, and a more regular and even appearance, but a too high length results in problems during the

spinning operation, depending on the specific spinning technique and apparatus used. Therefore, the average fibre length is preferably between 50 and 140 mm, more preferably between 60 and 100 mm, and still more preferably between 65 and 95 or even between 70 and 90 mm. Very good results have been obtained with an average fibre length of about 80 mm.

The single-strand spun yarn according to the invention comprises high strength and high modulus staple fibres that show essentially no crimp, the fibres not being, or only slightly textured. Crimp is a measure for the waviness of a fibre, and may be expressed as the difference between the length of the straightened or fully extended fibre and the crimped length, that is the length of the fibre when substantially free from external restraint. Showing essentially no crimp is herein understood to mean that the length of the staple fibres in unstrained condition is at least 80% of the straightened length. Preferably, the crimped length is at least 90% of the straightened length, even better at least 95%. Showing essentially no crimp is further understood to include no permanent crimp. For example, UHMwPE staple fibres may show some crimp that may have been introduced during staple making, but this crimp is not permanent, since it will essentially disappear upon exposing the fibres to elongational forces, which may e.g. occur during spinning. This presents another advantage of choosing UHMwPE fibres as staples fibres in the spun yarn according to the invention.

The single-strand spun yarn according to the invention comprises at least 30 mass% of said high strength and high modulus staple fibres. The spun yarn may further comprise up to 70 mass% of one or more other staple fibres of lower strength, like natural fibres or synthetic fibres, to make a blend yarn. The average length of these staple fibres is chosen such that they are compatible with the spinning process applied, which process is determined by the average length of the high performance staple fibres. Suitable examples of such secondary staple fibres include wool, polyolefin, polyester or polyamide fibres.

The spun yarn, and the staple fibres, may further contain the usual additives, like stabilizers, colorants, mineral particles, sizing agents, and the like. In a special embodiment, the staple fibres contain mineral particles, e.g. small ceramic particles that further improve the mechanical performance of the yarn, especially cut-resistance.

The choice of the other staple fibres, e.g. type, length, dpf and amount, and/or of additives is mainly determined by the ultimate yarn properties that are desired, and can be made by the skilled person using standard knowledge or

routine experimentation.

Preferably, the spun yarn according to the invention comprises at least 50, 60, 70, 80 or even 90 mass% of said high performance staple fibres, because this results in higher mechanical strength of the yarn, and in better performance of products made there from. For this reason, the spun yarn according to the invention most preferably comprises essentially only said staple fibres. It has surprisingly been found, that a yarn consisting essentially of said high performance staple fibres already shows good properties when about 30 fibres are present in a cross-section, whereas it is generally accepted that spun yarn should comprise a minimum of about 45 fibres.

The single-strand spun yarn according to the invention has a twist level characterized by an α twist coefficient of between 60 and 100 $t.m^{-1}.(m/g)^{-1/2}$. The optimum in twist level of a yarn is dependent on the titre of the yarn. Therefore, the α twist coefficient is used, rather than the actual twist level. The α twist coefficient characterizes the twist level of a yarn according to the Koechlin equation: $T = \alpha (Nm)^{1/2}$, wherein T is the twist level expressed as the number of turns per meter ($t.m^{-1}$) and Nm is the metric yarn count (1000/tex, or m/g). This twist coefficient is also referred to as (metric) twist factor, or twist multiplier; see for example at http://www.textile.org.uk/Glossary/t.htm.

A certain minimum twist level is needed to provide the yarn a desired level of integrity or coherency, and higher strength. Increasing the twist level will improve these properties, but too high a twist level, i.e. α coefficient above 100, may reduce strength again, induce spontaneous untwisting of free ends, and increase liveliness. Therefore, the α twist coefficient is preferably between 65 and 95, more preferably between 70 and 90, or even between 75 and 85, and most preferably about 80 $t.m^{-1}.(m/g)^{-1/2}$.

The spun yarn according to the invention may have a linear density, also referred to as titre, or expressed as yarn count, which varies within wide limits. Generally, the spun yarn has a titre of from 30 to 2500 dtex. In view of applications like protective garments and clothing, the yarn titre is preferably from 100 to 1600 dtex, even more preferably from 200 to 1200 dtex.

The single-strand spun yarn according to the invention typically has a tensile strength of at least 2,5 cN/dtex, depending on the type and amount of high performance staple fibres. Preferably, the spun yarn has a tensile strength of at least 3, 5, 7,5, 10, or even at least 12,5 cN/dtex. Such a high strength can generally be obtained if the spun yarn comprises a relative high amount of high performance staple

fibres. It has been found that the spun yarn according to the invention typically has a strength of at least about 40%, or even at least 45% of the strength of the precursor yarn (corrected for the amount of the staple fibres derived there from in the spun yarn).

The spun yarn according to the invention has surprisingly good cut-resistance. For a yarn comprising essentially only high performance staple fibres values at the same, or even higher level compared with corresponding filament yarn of similar titre have been obtained.

The spun yarn according to the invention may also have been provided with a coating layer. Such coating layer may comprise a typical spin finish to allow easier handling and processing in subsequent operations as is commonly applied in textile industry, a compound or composition to enhance adhesion upon making composite articles, or a binder composition that further enhances yarn integrity and strength. Typical examples of the latter include polyurethane or polyolefine-based binder compositions.

The invention also relates to a process for making the single-strand spun yarn according to the invention, comprising the steps of

a) making staple fibres having an average fibre length of between 40 and 180 mm, and essentially no crimp from a precursor continuous filament yarn, having a tensile strength of at least 16 cN/dtex; a tensile modulus of at least 700 cN/dtex; and a denier per filament of fibre of at most 18 dpf; and
b) spinning said staple fibres together with at most 70 mass% of other staple fibres of lower strength into a yarn, while applying a twist level characterized by an α twist coefficent of 60-100 $t.m^{-1}.(m/g)^{-1/2}$.

With this process, which can be performed using known spinning equipment, a single yarn of relatively high strength is obtained that is calm or balanced enough to enable further processing into various semi-finished and end-use products, like woven or knitted fabrics, different kinds of composite yarns, ropes and cords, or fishing lines without the need of first making a folded yarn. A further advantage of the process according to the invention is that various kinds of blended yarns can be made in a flexible manner.

The spinning step of the process according to the invention can be performed using known techniques, like ring spinning and open-end spinning. In view of the long staple length, ring-spinning techniques are preferred. In the process according to the invention also spinning equipment can be applied that is specially adapted for handling high performance staple fibres like UHMwPE fibres, such as

mentioned in WO 91/14029 A1 and WO 94/00627 A1.

In a preferred embodiment of the process according to the invention, staple fibres are made in step a) from high performance polyethylene filament yarn, preferably UHMwPE gel-spun yarn, by a stretch-breaking process. The advantage of this process is that a polyethylene spun yarn is made of relatively high strength and cut-resistance. The broader distribution of fibre length, compared to staple fibres made via a cutting process, further allows easy blending with other staple fibres, resulting in a more homogeneous yarn. Furthermore, starting from relatively high titre continuous filament yarn, spun yarns of widely varying titre can be made with mechanical properties, especially cut-resistance coming close to those of a filament yarn of similar titre.

The process according to the invention may further comprise a step, wherein a coating composition is applied to the as-spun yarn to form a coating layer. Such coating composition may comprise a typical spin finish to allow easier handling and processing of the yarn in subsequent operations, a compound or composition to enhance adhesion during subsequent making of composite articles comprising the yarn, or a binder composition that further enhances yarn integrity and strength. Typical examples of the latter include polyurethane or polyolefin-based binder compositions

The invention further relates to the use of the spun yarn according to the invention for making a semi-finished or end-use product. It is very surprising that a single-strand spun yarn can be used without any difficulties, because it is generally accepted in textile industries that folded yarns need to be used, because single yarns would not have enough strength and dimensional stability, that is they are not balanced or calm enough to allow reliable and trouble-free handling and processing.

In one embodiment, the spun yarn according to the invention is used for making a composite yarn. Composite yarns can be made by combining the single yarn according to the invention with at least one other filament yarn or monofilament. In this way, yarns with specific properties can be made, depending on the chosen at least one other yarn. Alternatively, a composite yarn can comprise the spun yarn according to the invention as a core layer surrounded by other fibrous material. The spun yarn may also be twisted together with another yarn. Composite yarns with very high cut-resistance can for example be made using the spun yarn according to the invention in combination with a metal wire, or glass or other inorganic fibres. Cut-resistant composite yarns with improved recovery after deformation result from a combination of yarn according to the invention and an elastic filament yarn like spandex. Examples of

various types of composite yarns comprising spun yarns are e.g. given in EP 0445872 A1 and US 6165084 A, but these publications do not disclose the use of single-strand spun yarns in such composite yarns.

In another embodiment, the spun yarn according to the invention, or a composite yarn comprising the spun yarn according to the invention is used for making cords or ropes. Cords of any size can be made by combining the single yarn according to the invention with at least one other yarn by merely folding together, or by making more complex structures by braiding, knitting or weaving. Rope is a term generally used for all kinds of cords or cordage more than 4 mm in diameter, and also includes cores of yarns covered by a braided sheath or plastic film.

In a further embodiment, the spun yarn according to the invention is used for making monofilament-like products, like fishing lines. Fishing lines are normally transparent or translucent monofilaments, but can alternatively be made from folded or braided multifilament polyolefin yarns by a process comprising at least partially heat fusing the surfaces of individual filaments within the yarn, as is described in EP 0740002 A1. The advantage of the use of the spun yarn according to the invention for making a monofilament-like product, wherein the staple fibres are made from polyolefin filaments, preferably UHMwPE filaments in view of their strength and heat fusing behaviour, is that a fishing line of desirable properties can be made with higher overall productivity and economics.

The invention therefore also relates to a process of making a monofilament-like product comprising a step of exposing a folded or braided yarn, comprising at least a spun yarn made from polyolefin staple fibres, to a temperature within the melting point range of the polyolefin for a time sufficient to at least partially fuse adjacent fibres. The melting point range of the polyolefin is the temperature range between the peak melting point of an non-oriented polyolefin and the peak melting point of a constrained highly-oriented polyolefin fibre, as determined by DSC analysis using a scan-rate of 20°C/min. The advantage of this process is that translucent or semi-transparent monofilament-like products having a low relative density can be made at higher overall production rate and lower overall costs compared with monofilament production or with the process known from EP 0740002 A1 wherein monofilament-like products are made by fusing of multifilament polyolefin yarns. The products obtainable by this process are useful as, for example, fishing lines. Preferably, in this process according to the invention a spun yarn according to the invention, wherein the staple fibres are polyolefin fibres, is applied. The monofilament-like product thus obtained

shows a surprisingly high retention of strength after a knot has been applied to the product.

In a further embodiment, the spun yarn according to the invention, or a composite yarn comprising the spun yarn according to the invention is used for making fabrics. All known methods of making fabrics may in principle be chosen. Suitable examples of fabric making techniques include knitting, weaving, braiding, or tufting. Preferably, the spun yarn is used for making a fabric with techniques like knitting and weaving, because the properties of the spun yarn allow manufacturing of fabrics with highly uniform appearance and good cut-resistance that can be applied for making all sorts of protective clothing and the like. Examples of the use of various types of yarns for making protective fabrics are e.g. given in EP 0445872 A1 and US 6155084 A, but these publications do not disclose the direct use of single-strand spun yarns. A knitted fabric made from the single-strand yarn according to the invention retains its shape, which is surprising since it is generally believed that at least a two-ply yarn should be used to prevent a knitted fabric from twisting out of shape.

The invention also concerns semi-finished and end-use products comprising the spun yarn according to the invention, as discussed above.

The invention will now be further illustrated by the following examples and comparative experiments.

Example 1

Multi-filament UHMwPE yarn, Dyneema® 1760SK60 (DSM High Performance Fibres, NL), having a titre of 1760 dtex, a tensile strength of 28 cN/dtex, a tensile modulus of 910 cN/dtex, and a denier per filament of fibre of 1 dpf was made into staple fibres by a stretch-breaking process, as for example described in EP 0445872 A1. The average length of the staple fibres was about 80 mm.

The staple fibres were subsequently spun into a single-strand yarn using NSC equipment of the long staple fibre type. A twist level of about 17 turns per meter was applied. The yarn obtained had a yarn count of about Nm 22 (450 dtex), meaning the twist coefficent was about 80 $t.m^{-1}.(m/g)^{-1/2}$. The spun yarn showed little liveliness, as was demonstrated by cutting a length of 100 cm, holding it vertically fixed at only one end, and observing hardly any tendency to twist.

The tensile strength and the tensile modulus were determined on multifilament or spun yarns as specified in ASTM D885M, using a nominal gauge length of the fibre of 500 mm, a crosshead speed of 50%/min and Instron 2714 clamps.

On the basis of the measured stress-strain curve the modulus is determined as the gradient between 0.3 and 1% strain. For calculation of the modulus and strength, the tensile forces measured are divided by the titre, as determined by weighing 10 metres of fibre. Cut-resistance was measured following the procedure described in EN 388. The results have been summarized in Table 1.

The single-strand yarn could be further processed on a Shima Seiki Gauge 13 seamless glove machine into a protective glove without any difficulties, in combination with about 10 mass% of an elastic yarn (Lycra®). The glove made had a very regular appearance and did not deform or twist afterwards.

Comparative experiment A

Mechanical properties and cut-resistance of a continuous filament yarn of titre 440 dtex (Dyneema® SK65) were measured for comparison, results are given in Table 1.

Comparative experiment B

Analogous to Example 1, the staple fibres were spun into a yarn, be it that a twist level characterized by a twist coefficient of about 110 $t.m^{-1}.(m/g)^{-1/2}$ was applied. Apart from difficulties encountered in spinning the yarn, the yarn produced showed strong tendency to curl around itself. Nevertheless, further processing by knitting of a fabric was carefully started, but had to be stopped quickly, because the yarn started to twist itself around the needles of the machine and breakage of some needles.

Example 2

Example 1 was repeated, but a yarn of count Nm 44 (225 dtex) was made, applying a twist level equivalent to a twist coefficient of about 80 $t.m^{-1}.(m/g)^{-1/2}$. Mechanical properties and cut-resistance results are given in Table 1.

Comparative experiment C

Mechanical properties and cut-resistance of a continuous filament yarn of titre 220 dtex (Dyneema® SK65) were measured for comparison, results are given in Table 1.

Table 1

	Yarn type	Mechanical properties			Cut-resistance	
		Tensile strength (cN/dtex)	Tensile modulus (cN/dtex)	Elongation at break (%)	Index	level
Example 1	Single-strand staple yarn; 450 dtex	15,1	122	4,7	4,02	2
Comp. Exp. A	Filament yarn; 440 dtex	31,2	1051	3,5	3,27	2
Example 2	Single-strand staple yarn; 225 dtex	15,0	153	4,28	2,04	1
Comp. Exp. C	Filament yarn; 220 dtex	31,6	1026	3,34	2,01	1

CLAIMS

1. Spun yarn made from staple fibres, which yarn consists of a single strand comprising at least 30 mass% of staple fibres that have been obtained from a precursor continuous multifilament yarn having a tensile strength of at least 16 cN/dtex; a tensile modulus of at least 700 cN/dtex; and a denier per filament of fibre of at most 18 dpf;
which staple fibres have an average fibre length of between 40 and 180 mm; and essentially no crimp;
and which spun yarn has a twist level characterized by an α twist coefficent of 60 - 100 $t.m^{-1}.(m/g)^{-1/2}$.
2. Spun yarn according to claim 1, comprising at least 30 mass% of UHMwPE staple fibres that have been made via a stretch-breaking process.
3. Spun yarn according to any one of claims 1-2, wherein the average fibre length is between 60 and 100 mm.
4. Spun yarn according to any one of claims 1-3, comprising at least 50 mass% of the indicated staple fibres.
5. Spun yarn according to any one of claims 1-4, consisting essentially of the indicated staple fibres.
6. Spun yarn according to any one of claims 1-5, wherein the α twist coefficient is between 70 and 90 $t.m^{-1}.(m/g)^{-1/2}$.
7. Spun yarn according to any one of claims 1-6, wherein the spun yarn has a titre of from 100 to 1600 dtex.
8. Spun yarn according to any one of claims 1-7, having a tensile strength of at least 5 cN/dtex.
9. Spun yarn according to any one of claims 1-7, having a tensile strength of at least 10 cN/dtex.
10. Process for making the single-strand spun yarn according to any one of claims 1-9, comprising the steps of
    a) making staple fibres having an average fibre length of between 40 and 180 mm, and essentially no crimp from a precursor continuous filament yarn, having a tensile strength of at least 16 cN/dtex; a tensile modulus of at least 700 cN/dtex; and a denier per filament of fibre of at most 18 dpf; and
    b) spinning said staple fibres together with at most 70 mass% of other staple fibres of lower strength into a yarn, while applying a twist level

characterized by an α coefficent of 60-100 $t.m^{-1}.(m/g)^{-1/2}$.

11. Process according to claim 10, wherein the staple fibres are made in step a) from UHMwPE gel-spun yarn by a stretch-breaking process.
12. Use of the spun yarn according to any one of claims 1-9 for making a semi-finished or end-use product; like a composite yarn, a cord or rope, a monofilament-like product, or a fabric.
13. Semi-finished or end-use product comprising the spun yarn according to any one of claims 1-9.

ABSTRACT

The invention relates to a spun yarn made from staple fibres, which yarn consists of a single strand comprising at least 30 mass% of staple fibres that have been obtained from a precursor continuous multifilament yarn having a tensile strength of at least 16 cN/dtex; a tensile modulus of at least 700 cN/dtex; and a denier per filament of fibre of at most 18 dpf; which staple fibres have an average fibre length of between 40 and 180 mm; and essentially no crimp; and which spun yarn has a twist level characterized by an α twist coefficent (Koechlin law) of 60 -100 $t.m^{-1}.(m/g)^{-1/2}$.

The single-strand spun yarn according to the invention can be made on existing spinning equipment, with high productivity and at relatively low cost; and is found to be calm enough to enable further processing into various semi-finished and end-use products without the need of first making a folded yarn. The spun yarn further shows surprisingly good tensile strength and cut-resistance.

The invention further relates to a process for making said single-strand spun yarn, to the use of said spun yarn for making various semi-finished and end-use products, and to such products comprising the spun yarn.